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A preliminary comparison of the trophic structure of some large marine ecosystems

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Abstract

Five large marine ecosystems are compared in respect to the signatures created by plots of number and average size of species by trophic level. Preliminary results suggest that these signatures are similar for similar ecosystems (here: Baltic Sea and Black Sea as examples of brackish, temperate ecosystems, and Caribbean and South China Sea as examples of tropical ecosystems), and different for different ecosystems (here: temperate vs tropical systems). Also, the shape and the position of the signatures appear to be predictable, as shown for the North Sea, which has a similar shape but intermediate position between the species-poor Baltic and Black Sea, and the species-rich tropical systems. Individual signatures can be interpreted and reveal special characteristics, as shown by the lower part of the Caribbean signature, which has a different trend then the other signatures, indicating that the Caribbean has relatively more herbivorous fishes. Fish data were extracted from www.fishbase.org. Preliminary signatures for cephalopods, marine mammals, and marine birds indicate the different roles of these groups in ecosystems. In the North Sea, vertebrates (fish, birds, marine mammals) and cephalopods are restricted to trophic levels above 3, with the exception of very few fish and bird species). Invertebrates are restricted to trophic levels below 3, again with very few exceptions.

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Introduction

There is wide agreement that modern fisheries management has to take into account not only prey and predators of a target species, but also its role in an overall ecosystem context. There are also increasing calls for ecosystem management. Yet our understanding of Large Marine Ecosystems (LMEs) is still limited. In this study we present an attempt to describe ecosystems by the trophic structures of important species groups. We use the signatures created by plots of number and average size of species by trophic level as conservative, long-term characteristics of LMEs. We try to advance our understanding of LMEs by comparing such signatures between groups of organisms and between LMEs. Our first hypothesis is that a given group of organisms will show similar signatures in similar LMEs, and vice-versa. Our second hypothesis states that different groups of organisms will have typical and different signatures.

Material and Methods

For the purpose of this study we used fish, cephalopods, marine mammals and marine birds as groups of organisms. We used the Baltic and the Black Sea as presumably similar brackish, temperate, and species-poor ecosystems. We used the Caribbean and the South China Sea as examples of tropical, species-rich ecosystems. We also looked at the North Sea as an example of an intermediate ecosystem in the sense that it is marine, temperate, and more species-rich than the Baltic and the Black Sea.

For fishes we used trophic level and average maximum length data contained in FishBase (Froese & Pauly, 2000; www.fishbase.org). Assignment to LMEs was also derived from FishBase. For cephalopods we used data on distribution and food from Jaeckel 1958, Roper et al. 1984, and from CephBase (www.cephbase.utmb.edu/) (Wood et al. 2000). For marine mammals we used trophic levels from Pauly et al. (1998). For marine birds of the North Sea we used Bezzel 1984, Meltofte et al. 1994, and Skov et al. 1995. Trophic levels (trophs) were calculated from diet composition data as Troph = 1 + mean troph of the food items (Pauly and Christensen, 2000). If no diet composition but individual food items were known, trophic level was estimated using a Monte Carlo routine described in Pauly and Sa-a (2000). Both routines are implemented in the software package TrophLab that can be downloaded at www.fishbase.org/download/. If no food information was available for a given species it was assigned the mean troph of congeners or of the respective family.

Results and Discussion

Figure 1 shows the trophic signatures of fishes in the Baltic, the Black Sea, the North Sea, the Caribbean and the South China Sea, with total number of species increasing in this sequence. Despite the considerable difference between these ecosystems in terms of salinity, size, temperature, and species numbers, the signatures are strikingly similar: in all ecosystems fishes cover the whole range of trophic levels, from herbivores near 2.0 to top predators at above 4.5. Both herbivores and top predators are at or below 5% of total species numbers. Highest species numbers are always present around troph 3.2, i.e., with first-level predators feeding mainly on herbivorous organisms. The signatures of the brackish, species-poor Baltic and Black Sea are more similar to each other than to the marine, more speciose North Sea, which has more top-

predators and fewer lower-level species, thus resembling more the structure of the tropical systems. The Caribbean signature is the only one where the lower leg is bent to the right, indicating a relative higher number of herbivorous fishes than in other systems.

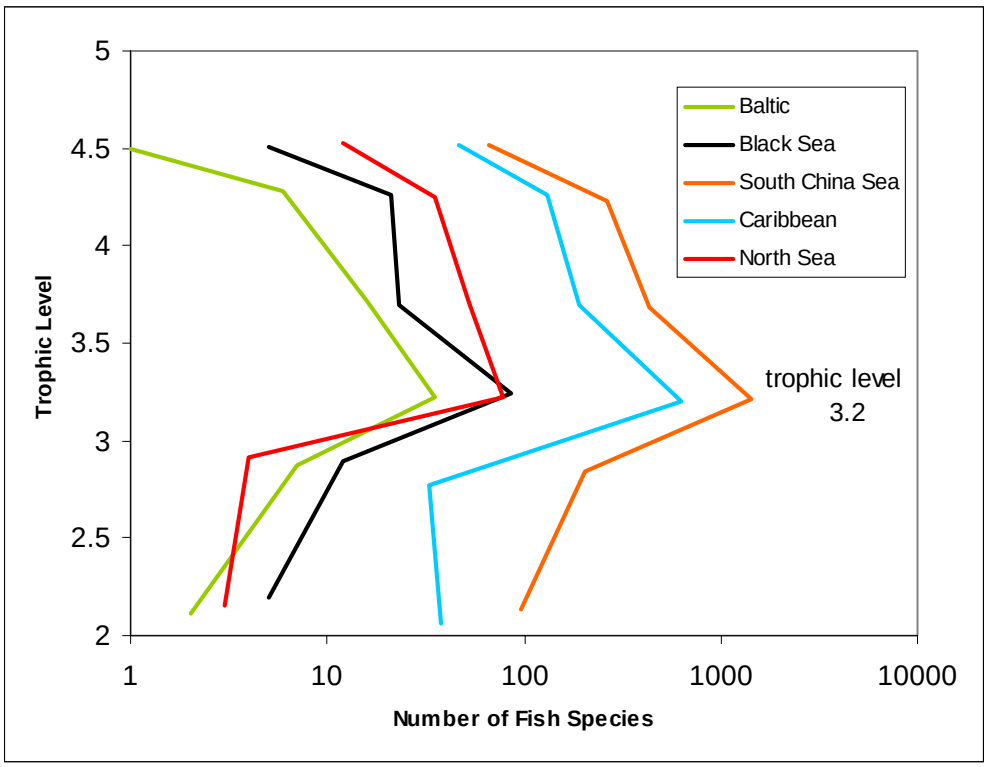

Figure 1. Trophic signatures of fishes in five large marine ecosystems. Note that all signatures have similar shapes and a maximum around trophic level 3.2.

Figure 2 shows the mean length of fishes per trophic level in the five ecosystems. Again these signatures are very similar across the different ecosystems, with top-predators being clearly larger than first-order predators, and herbivorous fishes being slightly larger. When compared with Fig. 1 it becomes clear that the high number of fish species around trophic level 3.2 are mostly small-sized predators of presumably zooplankton and small benthic invertebrates. As expected, mean size is overall lower in the tropical systems compared to the temperate ones. The signature of the Baltic somewhat differs from the others, probably due to the faunal mix of marine fishes in the western Baltic and increasing numbers of freshwater fishes in the north-eastern Baltic.

Fig. 3 shows a comparison of the signatures of cephalopods, marine mammals, birds and fish in the North Sea. Only birds and fish species occupy all trophic levels, with a striking similarity in number of species at lower levels, including both signatures peaking near trophic level 3.2. At the higher trophic levels, birds and fish have similar numbers of top predators above level 4.5, but birds have strikingly few species of second-order predators at levels between 3.5 and 4.0, a trend that should be further analysed in comparison with other ecosystems. Cephalopods and marine mammals are restricted to the higher trophic levels between 3 and 5. Because of their overall low species numbers (20 and 22, respectively) their signatures have to be viewed with some caution,

as these may change when different diet studies result in species being moved between trophic levels. Nevertheless, the peak at 4.2 for marine mammals confirms their role as top predators in the North Sea; a plot of all marine mammals in the world shows a similar signature also peaking at 4.2. Fish clearly contribute the highest number of species above trophic level 3. Cephalopods are the only invertebrate group present and restricted to trophic levels larger than 3.0 because they are known as voracious, highly mobile predators (Rodhouse & Nigmatullin 1996) dominating the nekton besides fishes and marine mammals.

Figure 4 shows total species numbers per trophic level for the North Sea, resulting in the typical pyramid structure that is well known from biomass studies. Looking at Fig. 4 from an evolutionary perspective it seems that the 4 groups (3 vertebrates (fish, birds, marine mammals), one invertebrate (cephalopods)) that together dominate the upper trophic levels (>= 3) of marine ecosystems are absent or exceptions at the lower trophic levels (< 3), which are dominated by large numbers of invertebrate species (e.g. about 1500 species of benthic and 1000 species of planktonic invertebrates (Rumohr, pers. comm.).

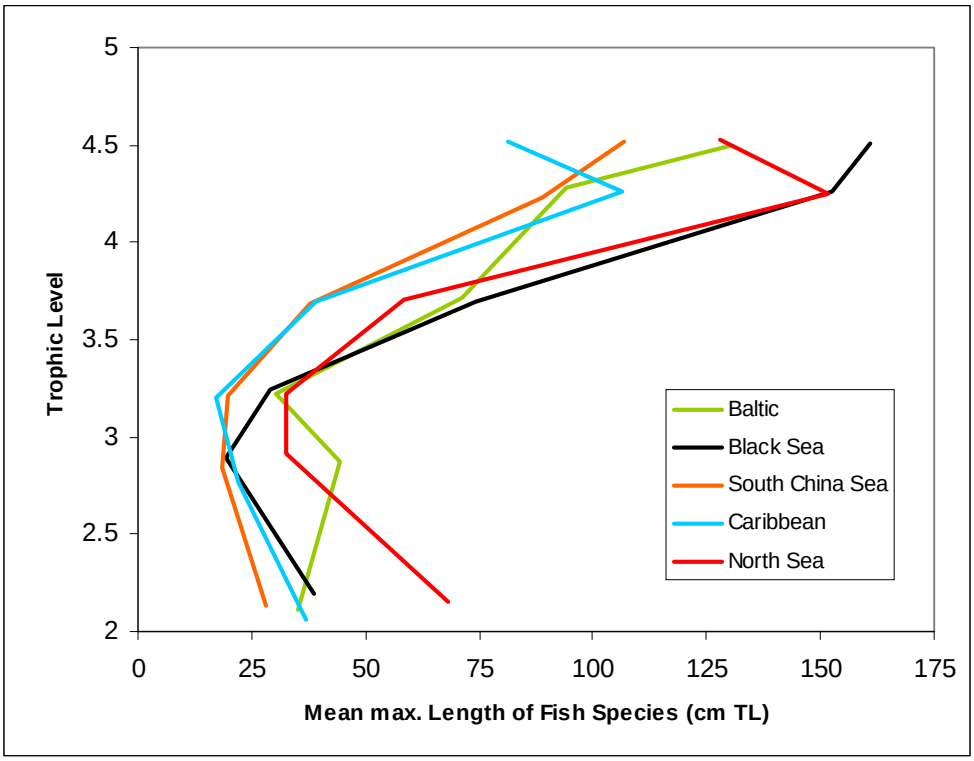

Figure 2. Mean maximum length of fishes at different trophic levels, for five large marine ecosystems.

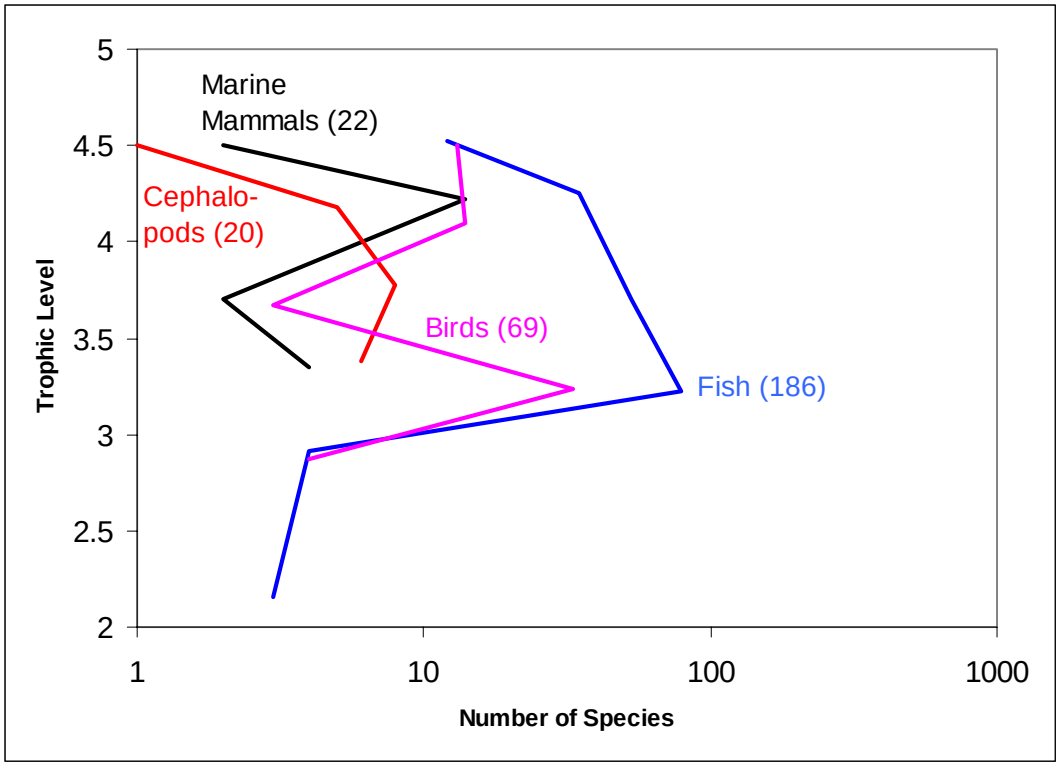

Figure 3. Number of species per trophic level for four groups of organisms in the North Sea.

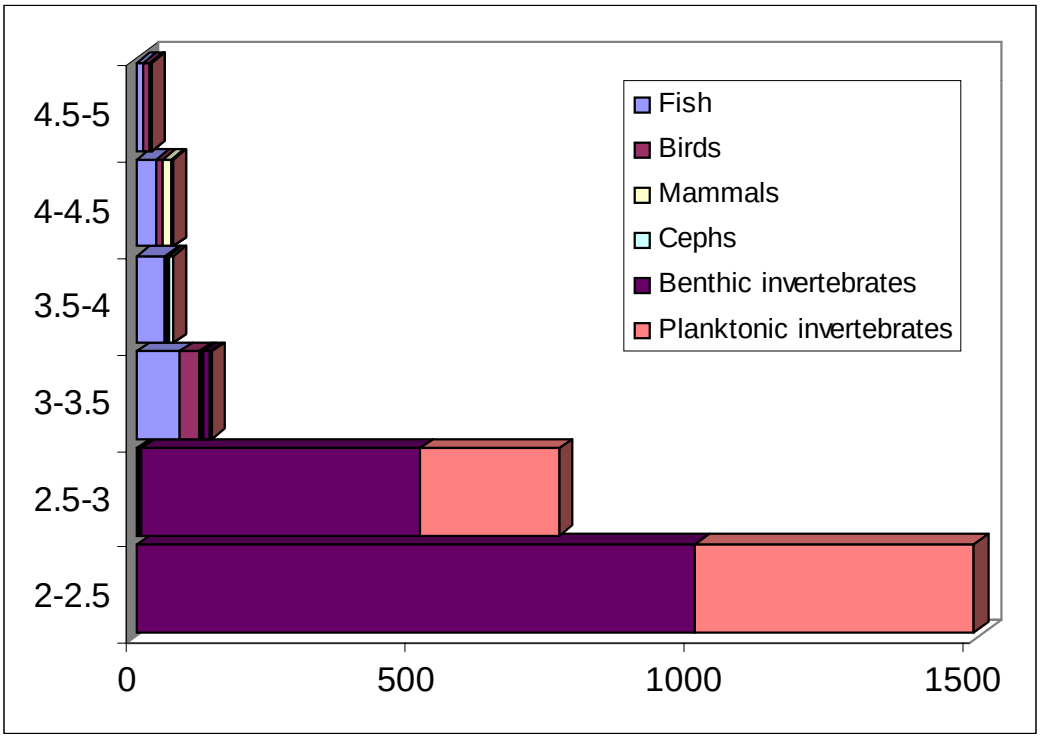

Figure 4. Numbers of North Sea species per trophic level. About 1500 benthic invertebrates and 1000 planktonic invertebrates are assumed, with most being mainly herbivores, fewer being omnivores, and very few being maily first-level predators.

In conclusion, the hypotheses presented in the introduction were supported by the preliminary analysis of 4 groups of organisms in 5 ecosystems: fish showed similar signatures in similar LMEs, and still typical but different signatures in clearly different LMEs. The four species groups also had characteristic, different signatures. The very strong separation of vertebrates and cephalopods at trophic levels above 3 and of invertebrates below 3 was an unexpected result. Trophic signatures thus appear to be a useful tool to better understand the role different groups of organisms play in different ecosystems. The signatures may help to create a classification of large marine ecosystems. Polar and upwelling ecosystems would be interesting objects to study next. Also, the organisms at the lower trophic levels and that form the basis of the food web need more attention.

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References

Bezzel, E. (1985): Kompendium der Vögel Mitteleuropas. Nonpasseriformes - Nichtsingvögel. Aula Verlag, Wiesbaden.

Froese, R. & D. Pauly. Editors (2000): FishBase 2000: concepts, design and data sources. ICLARM, 344 p. With 4 CD-ROMs.

Jaeckel, G.A. (1958.): Cephalopoden. *In* Grimpe, G. & E. Wagler (eds.*): Die Tierwelt der Nord- und Ostsee* **37**:481-723.

Meltofte, H., J. Blew, J. Frikke, H.-U. Rösner & C. J. Smit (1994): Numbers and distribution of waterbirds in the Wadden Sea. Results and evaluation of 36 simultaneous counts in the Dutch-German-Danish Wadden Sea 1980-1991. *IWRB Publication* **34** *& Wader Study Group Bulletin* **74** (*Special Issue)*:1-192.

Pauly, D., A.W. Trites, E. Capuli & V. Christensen (1998): Diet composition and trophic levels of marine mammals. *ICES Journal of Marine Science* **55**:467-481.

Pauly, D. & V. Christensen (2000): Trophic level of fishes. p. 181 *In* Froese, R. & D. Pauly (eds.), FishBase 2000: concepts, design and data sources. ICLARM, 344 p.

Pauly, D. & P. Sa-a (2000): Estimating trophic levels from individual food items. p. 185 *In* Froese, R. & D. Pauly (eds.), FishBase 2000: concepts, design and data sources. ICLARM, 344 p.

Rodhouse, P.G. & Ch.M. Nigmatullin (1996): Role as consumers. In Clarke, M. (ed.), The role of cephalopods in the world's ocean. *Philosophical Transactions of the Royal Society of London Series B* **351**:1003-1022.

Roper, C.F.E., M.J. Sweeney & C.E. Nauen (1984): FAO species catalogue. Volume 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. *FAO Fisheries Synopsis* **125(3):**1-277.

Skov, H., J. Durinck, M. F. Leopold & M. L. Tasker (1995): Important bird areas for seabirds in the North Sea including the Channel and the Kattegat. BirdLife International, Cambridge.

Wood, J.W., C.L. Day, P. Lee & R.K. O'Dor (2000): CephBase: testing ideas for cephalopod and other species-level databases. *Oceanography* **13**:14-20.